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EFFECTS OF FURROW DIKING ON CORN RESPONSE TO LIMITED AND FULL SPRINKLER IRRIGATION

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Summary: Furrow diking of fully and limited irrigated corn improved grain yields across three growing seasons compared with two other surface tillage systems. The high irrigation application rates of spray systems may lead to reduced water storage capacity of furrow dikes under these conditions due to dike erosion. In more normal growing seasons, limited irrigation of corn (a 50% irrigation reduction) produced grain yields that were only reduced 39% (1997) and 22% (1999) in comparison with a more fully irrigated treatment. The drought season of 1998 clearly showed the risks associated with not fully irrigating corn in this semi-arid environment when an 85% yield reduction occurred with limited irrigation.

Keywords: Furrow diking, Corn yield, Rainfall, Irrigation, Sprinkler irrigation, Soil water

EFFECTS OF FURROW DIKING ON CORN RESPONSE TO LIMITED AND FULL SPRINKLER IRRIGATION [1/]

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ABSTRACT

Corn (*Zea mays* L.) is a major irrigated crop in the Southern High Plains of the United States that is usually fully irrigated. The trend has been toward center pivot sprinklers equipped with low pressure, closely-spaced spray heads that have a large instantaneous application rate that can cause surface water redistribution and/or runoff. This 3-yr study (1997 through 1999) evaluated three surface tillage systems for corn under two irrigation regimes in a semi-arid environment at Bushland, TX. The main treatments were furrow diking, clean furrows, and flat tillage. Imposed upon these tillage treatments were two irrigation regimes—full soil water replenishment (FI) and limited irrigation (LI), which was irrigated at the same time as FI but with one-half of the irrigation amount. Irrigations were applied using a lateral-move sprinkler system equipped with low-drift spray nozzles spaced 1.5-m apart with heads about 1.8 m above the ground and nozzled to simulate the flow rates at the outer end of a 400-m system with an irrigation capacity of 8 mm d^{-1}. Each plot was 13.7 m wide (eighteen 0.75 m rows) with a water isolation border plot between the irrigation treatments. Yields were significantly ($P<0.05$) affected by year and all treatments. The 1997 and 1999 yields were similar, but the1998 yields were reduced by a combination of drought and disease. Furrow diking did significantly increase corn yields across years and irrigation regimes in this semi-arid environment.

INTRODUCTION

Corn (*Zea mays* L.) is a major crop grown on the U.S. Southern High Plains. In this region, corn typically has some of the greatest mean county yields (USDA-NASS, 1999) because almost all the corn is produced under full irrigation regimes. Corn has a large seasonal irrigation requirement (Musick et al., 1990) and a large evapotranspiration (ET) demand (Howell et al., 1997 and 1998) in the Southern High Plains region (Texas and New Mexico High Plains, Oklahoma Panhandle, Southwestern Kansas, and Southeastern Colorado). The Texas High Plains, like the whole region, has dramatically shifted from predominately graded furrow irrigation (90% in 1958) to slightly more than 50% sprinkler (mainly center pivot sprinklers) by 1994 (TWDB, 1996). The change in irrigation technology has reduced water applications and contributed to sustained irrigated production in this region (Musick and Walker, 1987). The Texas High Plains irrigated area in 1994 exceeded 1.5 million ha and represented nearly 50% of all the cropped area in the region (TAS, 1999). Center pivot sprinklers, now growing in popularity (Musick et al., 1988), are well suited for irrigation in this region where water is a far more limited resource for irrigated agriculture than land (Splinter, 1976). Musick et al. (1990)

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subdivided the Texas High Plains into three major climatic and crop zones – North Plains, Central Plains, and the Southern Plains. The southern portion of the Texas High Plains is dominated by cotton (*Gossypium hirsutium* L.), while the northern portion is mainly a wheat (*Triticum aestivum* L.) and corn region. The central portion is a mixture of these main crops. Sorghum (*Sorghum bicolor* (L.) Moench.) is produced in all subdivisions, but corn is the only grain crop that is consistently irrigated at its "full" irrigation requirement. Wheat, cotton, and sorghum are often deficit irrigated.

Irrigated corn planted area dramatically escalated from the late 1960s until the late 1970s in this region. It declined dramatically, too, during the next decade because of many economic factors (high energy prices, poor commodity prices, high interest rates, etc.). But irrigated corn area in the Texas High Plains has approached 400,000 ha since the mid 1990s. Corn production area in the central portion of the Texas High Plains has stabilized at around 200,000 ha, but the northern portion (north of Amarillo) has dramatically expanded its corn production area and shows signs of continual expansion. This area has substantial groundwater resources (Opie, 1993); however, great concern remains about resource economics and irrigated agriculture's sustainability in this region (Vaux, et al., 1996; Gardner, et al., 1996).

Corn has been grown on a wide-scale commercial basis for about 30 years in the Texas High Plains (a relatively short history compared with the other major irrigated crops in the region). Recent yields have often exceeded 12 Mg ha^{-1} in the Southern High Plains; however, more it is significant that fully irrigated corn in the Texas High Plains has a higher ET compared with other sites in the Great Plains, United States, and world. Also, corn yields have shown a rather consistent increase during the past 20 years in this region. The mean regional irrigated sorghum yield has remained largely unchanged during this period, while both irrigated wheat and cotton yields have increased, but not as consistently as the corn yields. Generally, the sorghum and wheat crops are considered more drought tolerant than corn and are produced under a wider diversity of irrigation capacities (flow rate per unit land area) that are not considered adequate for corn.

Surface Tillage for Sprinkler Irrigation

Various tillage techniques have been proposed to provide temporary detention of sprinkler applied water to reduce surface redistribution and runoff (Aarstad and Miller, 1973; Oliveira et al., 1987; Kincaid et al., 1990; and Kranz and Eisenhauer, 1990). The surface tillage types are usually implanted reservoir (dammer diking) or basin tillage (furrow diking) that places small dams at regular or systematic distances along a furrow (Jones and Stewart, 1990). The implanted reservoirs can be used in flat or bedded culture, while basin tillage requires a furrowed or bedded culture. Lyle and Dixon (1977) described a diking tool designed to capture rainfall and irrigations for beds and furrows. Furrow diking, traditionally, is used in a "clean" tilled system or occasionally in conservation ridge-till systems; however, implanted reservoirs can be used in higher residue conservation till systems (Oliveira et al., 1987). The commercial dammer-diker implement is used together with deeper chiseling. Oliveira et al. (1987) reported that the chiseling improved the hydraulic conductivity and that it was of greater importance in reducing runoff than the reservoir storage detention, which varied with implement depth from 16 to 21 mm and declined to 9 to 16 mm during the season. Aarstad and Miller (1973) used handmade basins spaced 0.6 m apart in furrows and found that they effectively eliminated runoff with applications of 5 to 9 mm on slopes from 3 to 7%. Basins were better than a 11 Mg ha^{-1} of incorporated alfalfa (*Medicago sativa* L.) hay. Mickelsen and Schweizer (1987) studied continuous corn under high (384 kPa) and low (140 kPa) pressure center pivot system applicators in Eastern Colorado that demonstrated 30% greater runoff with the low pressure system with conventional tillage on a 3.8% slope, but two ridge till systems reduced irrigation runoff to between 1 to 4%. Hackwell et al. (1991) studied runoff and infiltration with LEPA (low energy, precision application) with reservoir tillage, and they found increased infiltration and reduced runoff. They reported reservoir storage volumes near the end of the season that varied from 3 L for higher compaction to almost 4 L for lower compaction, and these had declined due to siltation from intense spring rains.

Basin tillage is an integral component of low energy, precision application (LEPA) (Lyle and Bordovsky, 1981). Howell et al. (1995) reported a rainfall storage volume for furrow dikes constructed on 0.75 m rows with a commercial diker of 50 mm. This would decline by one-half to 25 mm if alternate furrow LEPA irrigation was used. The smaller storage capacity of 8 to 12 mm with dammer-diker pits for alternate row LEPA would not provide enough storage capacity to avoid surface redistribution and/or runoff unless one or two day irrigation frequencies were used, which are nearly impractical with most center pivot sprinklers. Schneider and Howell (1999) measured runoff from 20-m long plots of 0 and 12% with spray irrigation with and without furrow dikes, respectively; while with LEPA, they reported 22 and 52% runoff with and without dikes, respectively. For water applied in the "bubble" mode to alternate rows with ridge-till corn, Buchleiter (1992) measured runoff under LEPA of 30% of the applied water on slopes of 3 and 55% runoff from an 8% slope. Lyle and Bordovsky (1983) reported 2-year mean application efficiencies of 99% for LEPA, 84% for sprinkler, and 87% for furrows using basin tillage, and 88% for LEPA, 81% for sprinkler and 86% for furrow using conventional tillage. Hanson et al. (1998) studied the effects of furrow diking intervals and soil infiltration and reported that the actual infiltration uniformity was much less than the static hydraulic nozzle discharge uniformity of 95%. Fangmeier et al. (1990) recommended a furrow dike spacing of 2 m to obtain a uniformity coefficient of 0.8 and developed a "double-ended" drag sock to reduce dike erosion. Solomon et al. (1994) used the LEPA concept with basin tillage implemented on straight rows with a center pivot rather than circular rows and reported a storage capacity of nearly 66 mm.

Reservoir tillage uses a combination chisel with a paddle wheel to implant small reservoirs. Kincaid et al. (1990) reported reservoir tillage prevented runoff that was up to 43% of the applied water on conventionally tilled plots even for slopes up to 12%. Coelho et al. (1996) reported storage volumes for only about one days' ET of corn. Kranz and Eisenhauer (1990) and Spurgeon et al. (1995) compared reservoir tillage with conventional tillage and chiseling. Using a 50-mm application depth for application rates from 113 mm h^{-1} to 149 mm h^{-1}, Kranz and

Eisenhauer (1990) measured runoff percentages of 25, 12, 8, and 41% for conventional tillage, basin tillage, reservoir tillage, and chiseling, respectively, on a 10% slope, and only 5, 5, and 8% runoff for conventional tillage, reservoir tillage, and chiseling, respectively on a 1% slope. Spurgeon et al. (1995) reported that reservoir tillage was more effective than basin tillage in maintaining soil water and enhancing crop yields on a 3.9% slope. They reported better results with low elevation spray application (LESA, low elevation spray application, or in-canopy spray) compared to LEPA in the bubble mode.

Surface Tillage for Rainfall Capture

Basin tillage was also developed for rainfall capture in semi-arid environments (Lyle and Dixon, 1977; Gerard et al., 1984; Jones and Clark, 1987, Jones and Stewart, 1990; Baumhardt et al., 1992 and 1993) for dryland crop production. Generally, positive yield responses have been found in years with storm intensity and/or amounts that would be expected to produce significant runoff. McFarland et al. (1991) reported a yield decrease with corn in a year with above-average rainfall but did not find corresponding reduced leaf or soil nitrogen decreases from N leaching. In a drier to more normal rainfall year, they found no effect of diking on corn yield in the subhumid climate. Unger (1992) reported no increase in soil water or crop yield for sorghum or wheat with blocked furrows compared with no-till alone in a semi-arid environment at Bushland. Mickelson and Schweizer (1987) reported growing season runoff that varied from 12 to 32% of rainfall with the least amount using a strip-rotary till system. Wiyo et al. (2000) indicated "tied-ridging" (another name for furrow diking) would be more effective on fine textured soils than on coarse textured soils and may lead to waterlogging with seasonal rainfalls more than 900 mm with fine textured soils.

Objective

Resource constraints and production relationships to irrigation are vital information required by resource economists, agronomists, and engineers to provide advice for water resource planning. The purpose of this paper is to summarize the effects of surface tillage and irrigation levels on corn production in the semi-arid environment of the U.S. Southern High Plains.

MATERIALS AND METHODS

This study was conducted at the USDA-ARS Conservation and Production Research Laboratory at Bushland, TX (lat. 35°11' N; long. 102°06' W; 1170 m elevation MSL) during the 1997, 1998, and 1999 growing seasons. The soil at this site is classified as Pullman clay loam (fine, mixed, superactive, thermic Torrertic Paleustoll), and the field slopes were approximately 0.3% or less. The soil is described by Unger and Pringle (1981) and Taylor et al. (1963) as slowly permeable because of a dense B21t horizon about 0.15 to 0.4 m below the surface. The plant available water holding capacity within the top 2.0 m of the profile is approximately 250 mm, but corn cannot fully exploit and extract the soil water below about 1.5 m (Tolk et al., 1998). A calcareous layer at about 1.5 m depth limits significant rooting and water extraction below this depth. This soil is common to more than 1.2 million ha of land in this region and about one-third of the sprinkler irrigated area in the Texas High Plains (Musick et al., 1988).

The cultural operations and agronomic information are given in Table 1. The plots were each 13.7 m wide (E-W) (18 rows spaced 0.75 m apart) and approximately 40 m long (N-S). Plots were arranged so a drainage way with a berm permitted the plots to drain to the S and E while blocking any runon from the north side of the plots. Each plot was bordered diked on the E and W sides, and a 4.6-m wide guard plot separated water treatments in the E-W direction to permit manual system speed changes to adjust the application amount. All cultural operations were performed with standard 6-row farm equipment. Sowing densities achieved mean field plant densities of 8 plants m^{-2} each year at harvest. Plots were seeded on previously summer fallowed areas each year.

The irrigation system was a Valmont[1/] (Valmont Industries, Inc.,Valley, NE) three-span lateral move sprinkler system with a pressurized water supply via a 100 mm ID hard hose from hydrants. The irrigation water was Ogallala groundwater pumped from wells into a 0.4 ha reservoir and then pumped to the irrigation system with an electric turbine pump through underground polyvinyl chloride (PVC) pipeline. Standard pump operating pressures at the reservoir supply pump were manually "choked" with a gate valve to about 310 kPa at 30 L s^{-1}. Operating pressures at the pull-tower were typically about 140 kPa. Senninger (Senninger Irrigation, Inc., Orlando, FL) LDN spray heads with double spray plates with 42 kPa pressure regulators (Senninger model PMR-MF) and 8.3 mm (#21) nozzles rated to flow at 0.465 L s^{-1} were spaced 1.5 m apart and about 1.8 m above the ground on PVC hose drops with 0.9 kg polyethylene (PE) weights to reduce wind swaying of the drops. The nozzle flow rates were selected to simulate the outer span of a 400-m long center pivot sprinkler with an irrigation capacity of approximately 8 mm d^{-1} (0.93 L ha^{-1} s^{-1}).

The experimental design was a complete randomized block design with three replications. The main treatments were surface geometries installed using various tillage regimes after planting including one that left the soil surface nearly flat (FT), one that formed a more traditional bed (BT), and one like the BT treatment but with furrow dikes (FD) installed with a trip-roll diker (Bigham Brothers, Inc., Lubbock, TX). Dike spacings varied but averaged about 1.8 to 2.0 m. The tillage plots and rows were perpendicular to the irrigation system travel path, and each plot was an entire span length with the next tower wheels running north of plot berm to prevent N-S water runon onto a plot. The experiment plot area was rotated each season to a previous summer-fallowed field area. Unreplicated, nonirrigated plots were maintained as a dryland check for all the tillage treatments.

[1/] The use of trade, firm, or corporation names is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Agricultural Research Service of any product or service to the exclusion of others that may be suitable.

The irrigation treatments were based on soil water depletion replenishment. The fully irrigated treatment (FI) was designated to receive near full soil water replacement for the depletion in the upper 1.5 m of the soil profile based while allowing about 25 to 30 mm for rainfall storage. The irrigation control was based on biweekly to weekly soil water measurements using a Campbell neutron probe (model 503DR, Campbell Pacific Nuclear Corp., Martinez, CA). The neutron probe was calibrated to the Pullman soil (Evett and Steiner, 1995), and 16-s readings were taken from 0.2 m to 2.4 m deep in 0.2 m increments. One neutron tube was installed in each replication of the furrow diked, fully irrigated (FD, FI) plots. The limited irrigation treatment (LI) was irrigated at the same time as the FI plots, but the system speed was doubled to apply one-half the amount that the FI treatment received. Each plot was gravimetrically sampled to 1.8 m in 0.30 m increments with a mechanical soil sampler at planting and following harvest. Samples from each layer were oven dried at 105°C to determine the soil water content and season depletion.

Yield was determined by hand harvesting two 6.56-m long row sections from differing planter passes for a 10 m^2 sample area. The plants and ears were counted. The ears were removed from the shucks and oven dried at 70°C until no mass change was observed. Then, the grain was shelled from the cob and weighed. Kernel mass was determined from 250 kernel sub-samples from each row sample. Row samples were averaged to determine each plot's yield parameters. Grain yields are reported at standard 15.5% water content (wet basis), and kernel mass is expressed on a dry basis. Data were analyzed using standard analysis of variance and mean difference methods using Sigma Stat (v2.03, SPSS Inc., Chicago, IL).

RESULTS AND DISCUSSION

The different environments of each season are characteristic of the climatic variability in the Southern High Plains (Table 2). Figure 1 illustrates the March (DOY 60) through September (DOY 273) rainfall recorded near the plot area in comparison to the 50-yr mean Bushland rainfall and the FI irrigations applied in each season. The 1997 season had a wetter than normal April and August months, but rainfall only averaged 8% below normal for the April through October growing season. The 1998 season was the driest summer in Bushland's history until a large rain occurred in late October. The April through October rainfall was still 26% below normal. Rainfall in 1999 was more evenly distributed, except for August and October, but the growing season rainfall was only 7% above normal. Growing season temperatures and grass reference ET were similar in 1997 and 1999. The advective and drier summer of 1998 was especially noticeable in the lower dew point temperatures and larger grass reference ET values in May and June coupled with the lower season rainfall. These season rainfall amounts and the fine textured soil would indicate the likelihood for yield increases from the furrow diking (Wiyo et al., 2000).

Soil Water

Total applied water (sum of irrigation plus rainfall) to FI was smallest in 1999 at 660 mm and largest in 1998 at 833 mm (Table 3). Soil water depletion (Table 3) did not vary significantly among the treatments according to the analysis of variance in 1997, but the differences between FI and LI were significant (P<0.05) in 1998, and the tillage treatments were slightly different (P<0.10) in 1999. These results are consistent with other dryland studies in semi-arid climates (Baumhardt et al., 1992 and 1993; Gerard et al., 1984; Jones and Clark, 1987; and Unger, 1992) that indicate furrow dikes would be more effective during above-normal rainfall seasons. The dense B21t horizon in the Pullman soil should likely minimize deep percolation losses reported for coarser soils (Wiyo et al., 2000). Soil water at harvest was significantly (P<0.05) affected by irrigation in 1997 and 1998, but not in 1999 when it was significantly less in the FT and BT treatments than in the FD treatment. Figure 2 shows the 2.5-m profile soil water contents for each season. These are generally the driest water contents since measurements were taken just prior to an irrigation. In all years, the soil water contents declined during the growing season from deeper water profile extraction (mainly in the 0.8 m to 1.5 m depths) that could not be replaced by the 25-mm application depths that are typical for center pivot sprinklers. Irrigations were applied as often as three times per week according to ET demand and the measured soil water contents. In 1997, the profile water contents were maintained well; however, in both 1998 and 1999 the soil water profile water levels for FI may have induced water deficits that could have reduced grain yields. The possible soil water deficits that were observed in 1998 and 1999, may have caused the reduced mean corn yields of the FI treatments in those years; however, the FI yields of the mean FD, FI treatment had a coefficient of variation less than 0.05 Mg ha^{-1}. Tolk et al. (1998) attributed less water uptake in the Pullman soil by corn to limited extraction from deeper profile levels (below 1.5 m). McFarland et al. (1991) reported increased soil water contents with rainfed corn with diking alone or with conservation tillage with or without diking in a below-average rainfall year. The high irrigation application rate of the spray system may have led to reduced water storage capacity of FD under the FI and LI regimes due to dike siltation from the walls similar to findings of Coelho et al. (1996), Kranz and Eisenhauer (1990) and Spurgeon et al. (1995).

Grain Yield and Yield Components

The grain yield was significantly affected by the growing season, surface tillage and irrigation regimes (Table 4). Grain yields were not significantly different between 1997 and 1999, but they were significantly less in 1998 due to the drought and a heavy infestation of smut (*Ustilago zeae*), particularly in the LI treatments. The smut infestation affected up to 75% of the ears in some of the LI plots. The smut was a regional problem that year due to the drought, high incidence of plant injury from the high wind speeds, and certain hybrid lines that had an unusual susceptibility to the disease, like Pioneer 3225 that we used that year. The low yields in the LI treatments in 1998 were responsible for the significant year X irrigation regime interaction (Table 4), while all other interactions were not significant. FD significantly increased the mean corn yield by 1.40 Mg ha^{-1}, while mean yields were not different between the FT and BT treatments. The irrigation treatment significantly reduced the mean yield in all years, but the greatest mean separation occurred in 1998.

The treatment mean grain yield, kernel mass, and kernels per unit area are given in Table 5. The LI treatment reduced grain yields of all tillage treatments in 1997 and 1998, but the FD treatment improved the LI yield in 1999. In 1997, the tillage treatments did not affect grain yield, but the LI treatments reduced kernel numbers due to a smaller ear size. In 1998 under the FI regimes, FD significantly increased grain yield compared with BT mainly by increasing kernel mass and ear size. In 1999, FD significantly increased grain yield in both the FI and LI treatments mainly through increased ear size since ear density was not different among the treatments. In 1999, the FD, FI grain yield was less than the FD, FI grain yields in 1997 and 1998 by almost 1.0 Mg ha^{-1}, and this may have been the result of the lower profile soil water in 1999 (Fig. 2) following the summer drought in 1998. At comparable N fertility, McFarland et al. (1991) did not report a yield benefit for FD of corn or an effect on leaf and grain N levels under rainfed conditions. They did indicate a tendency for FD to reduce yields under higher rainfall levels. Our results did not support that tendency under FD and full irrigation regimes or even under LI regimes on the Pullman soil.

Furrow diking treatments did not consistently increase corn yields with the LI regime, as anticipated, but FD did appear more effective in the normal to wetter season in 1999 (Table 5). Unfortunately, the smut damage to the LI treatments in the drought season of 1998 obscured any FD effects on grain yields when we would have expected the greatest benefit in line with McFarland et al. (1991). Schneider and Howell (1998) using FD reported no significant yield differences between overhead spray (comparable to this study) and LEPA in the sock mode. Their 100% and 50% irrigation mean grain yields were similar to the FI and LI treatment grain yields in 1997 and 1999 in this study. Tolk et al. (1998) reported smaller yields in 1996 for corn that was fully irrigated to meet ET use in rain sheltered lysimeters than we obtained for the FI treatment. They used a lower plant density (6 plants m^{-2}), which may have accounted partially for the lower yields. Their 50% irrigation treatment had comparable yields to our LI treatments in 1997 and 1999.

CONCLUSIONS

Furrow diking of fully and limited irrigated corn did significantly improve grain yields across three growing seasons compared with other surface tillage systems. Conservation tillage with higher plant residues may be as effective, though, with sprinkler irrigations in this semi-arid environment. The high irrigation application rates of spray systems may lead to reduced water storage capacity of furrow dikes under these conditions due to dike erosion. In more normal growing seasons, limited irrigation of corn (a 50% irrigation reduction) produced grain yields that were only reduced 39% (1997) and 22% (1999) in comparison with a more fully irrigated treatment. The drought season of 1998 shows clearly the risks associated with not fully irrigating corn in this semi-arid environment when an 85% reduction in yield occurred with limited irrigation (a 50% irrigation reduction).

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Table 1. Cultural operations and dates and agronomic information. Dates in parentheses are for the limited irrigated treatments.

Operation or Parameter	1997	1998	1999
N applied	Mar. 19 270 kg (N) ha^{-1}	Apr. 3 260 kg (N) ha^{-1}	Apr. 7 290 kg (N) ha^{-1}
P applied	Mar. 19 112 kg (P) ha^{-1}		
Sweep plowed field	Apr. 23	Apr. 21	Apr. 7
Installed plot borders	May 5	Apr. 22	Apr. 19
Planted corn (variety)	May 6 (PIO-3225)†	Apr. 23 (PIO-3225)	Apr. 21 (PIO-3162)
Soil sampled (water)	May 6	Apr. 23	Apr. 21
Pre-emergence herbicide		Apr. 30 2.2 kg ha^{-1} Atrazine‡ 1.1 kg ha^{-1} Metolachlor¶	Apr. 21 2.2 kg ha^{-1} Atrazine‡
Corn Emergence	May 15	May 7	May 4
Post emergence herbicide	May 16 0.9 kg ha^{-1} Atrazine‡		
Neutron tube installation	May 28	June 2	May 18
Cultivation and dike installation	June 6	June 2	June 2
Tassel emergence	July 16 (July 18)	July 12 (July 15)	July 12 (July 14)
Insecticide application	Aug. 3 0.04 kg ha^{-1} Bifenthrin§ Aug. 3 0.5 L ha^{-1} Dimethoate#	July 18 0.04 kg ha^{-1} Bifenthrin§ Aug. 3 0.5 L ha^{-1} Dimethoate#	Aug. 8 0.04 kg ha^{-1} Bifenthrin§
Harvested plots	Oct. 3	Sept. 16 (Sept. 10)	Sept. 8 (Sept. 7)
Soil sampled (water)	Oct. 10	Oct. 8	Oct 4

† Pioneer Hi-Bred International, Inc.

‡ (2-chloro-4-ethylamino-6-isopropylmino-s-trazine)

§ (2 methyl[1,1'-biphenyl]-3-yl) methyl 3-(2-chloro-3,3,3-trifluoro-l-propenyl)-2,2-dimethyl-cyclopropanecarboxylate

¶ 2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide

O,O-dimethyl S-[(methylcarbamoyl)methyl] (phosphorodithioate)

Table 2. Climatic data during the study period.

Month	Tmax†	Tmin‡	Tdew§	2-m Wind Speed	Solar Irradiance	Barometric Pressure	Rainfall	ET_o¶
	°C			$m\ s^{-1}$	$MJ\ m^{-2}\ d^{-1}$	kPa	mm	$mm\ d^{-1}$
1997								
Apr.	16.1	2.2	3.5	4.89	18.4	88.6	132.1	3.53
May	23.9	10.0	9.9	4.23	23.4	88.9	43.7	5.15
June	29.5	15.1	14.3	4.08	24.6	88.7	29.3	6.44
July	32.2	17.7	15.3	3.95	25.5	89.0	28.6	7.17
Aug.	30.3	16.9	16.6	3.24	21.4	89.2	82.5	5.40
Sept.	28.6	14.8	13.7	3.64	17.5	88.9	26.5	4.92
Oct.	22.0	6.7	6.0	4.60	15.7	88.9	19.1	3.89
1998								
Apr.	19.5	2.9	-1.1	4.56	21.9	88.6	8.1	5.11
May	29.3	11.4	4.0	4.17	25.2	88.6	27.6	7.63
June	32.4	14.8	2.8	4.79	28.0	88.6	1.2	9.59
July	34.3	18.6	11.7	3.64	25.3	89.2	26.6	8.12
Aug.	31.2	16.4	14.5	3.23	22.5	89.3	34.6	6.07
Sept.	30.9	15.0	12.2	3.38	19.1	89.0	1.0	5.70
Oct.	21.8	8.1	7.8	4.40	13.8	89.1	196.8	3.61
1999								
Apr.	20.6	5.9	4.4	4.22	17.2	88.9	87.8	4.63
May	23.6	9.1	9.3	4.25	23.4	88.7	65.9	5.03
June	29.1	15.1	14.8	4.28	25.1	88.9	67.3	6.26
July	31.3	17.9	17.0	3.84	26.0	89.1	99.4	6.61
Aug.	32.1	17.3	16.1	3.35	23.1	89.2	37.8	6.27
Sept.	26.0	12.7	11.3	4.16	18.0	89.1	63.7	4.86
Oct.	23.4	5.9	3.5	4.81	17.3	89.3	5.1	4.91
59-Year Historical Mean								
Apr.	20.9	3.6					27.7	
May	25.1	9.4					67.6	
June	29.9	14.8					75.2	
July	32.3	16.9					67.8	
Aug.	30.9	16.3					71.6	
Sept.	27.2	11.8					48.8	
Oct.	21.8	5.1					38.6	

†Air temperature maximum.
‡Air temperature minimum.
§Dew point temperature.
¶Reference grass evapotranspiration.

Table 3. Irrigations, growing season rainfall, and 1.8-m profile soil water depletion.

	1997		1998		1999	
Component	FI Depth	LI Depth	FI Depth	LI Depth	FI Depth	LI Depth
	---------- mm ----------					
Irrigation	559	279	749	419	337	174
Rainfall	211	211	84	84	323	323
Soil Water Depletion						
Diked (FD)	154	153	118	143	45	86
Flat (FT)	166	163	113	136	106	106
Open (BT)	145	190	123	147	105	102

Table 4. Analysis of variance for grain yield (Mg ha^{-1}) at 15.5% water content and main factor means.

Source	df	F	P
Year	2	78.04	<0.001
Tillage	2	13.12	<0.001
Irrigation	1	406.71	<0.001
Year X Tillage	4	1.25	0.306
Year X Irrigation	2	52.59	<0.001
Tillage X Irrigation	2	1.51	0.235
Year X Tillage X Irrigation	4	1.09	0.375
Error	36		
Total	53		

Main Factors	Yield
Year	Mg ha^{-1}
1997	11.22a†
1998	6.87b
1999	10.48a
Tillage	
FD	10.61a
FT	9.21b
BT	8.76b
Irrigation	
FI	12.59a
LI	6.46b

† Means within a factor followed by different letters are statistically different (P<0.05).

Table 5. Grain yields, kernel mass, and kernel number for 1997, 1998, and 1999 growing seasons for corn as affected by treatments.

Treatment	Grain Yield†	Kernel Mass†	Kernel Number
1997	Mg ha^{-1}	mg kernel^{-1}	kernels m^{-2}
Full Irrigation			
FD	14.49 a‡	273 a	4576 a
FT	13.58 a	260 ab	4408 a
BT	13.74 a	260 ab	4546 a
Limited Irrigation			
FD	8.86 b	242 c	3149 b
FT	8.62 b	248 bc	2991 b
BT	7.88 b	245 c	2760 b
$LSD_{0.05}$	1.81	13	574
1998			
Full Irrigation			
FD	14.19 a	269 a	4536 a
FT	11.75 ab	259 ab	3891 ab
BT	10.01 b	254 b	3382 b
Limited Irrigation			
FD	2.30 c	269 a	736 c
FT	1.50 c	259 ab	496 c
BT	1.47 c	254 b	497 c
$LSD_{0.05}$	2.59	14	746
1999			
Full Irrigation			
FD	13.38 a	274	4207 a
FT	11.18 b	261	3689 b
BT	10.87 b	262	3570 b
Limited Irrigation			
FD	10.40 b	264	3393 b
FT	8.44 c	269	2696 c
BT	8.63 c	258	2877 c
$LSD_{0.05}$	1.37	ns	344

† Grain yield expressed at 15.5% water content wet basis. Kernel mass is expressed on a dry basis.

‡ Means within a year followed by different letters are statistically different ($P<0.05$).

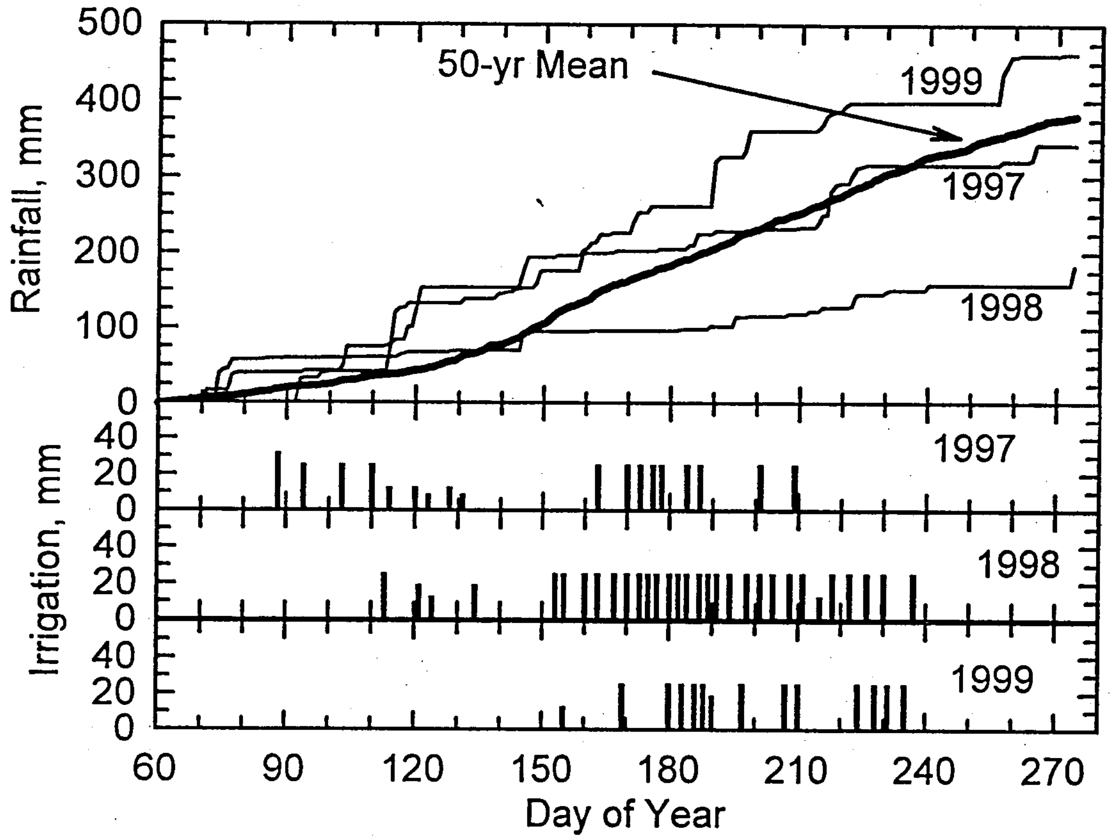

Figure 1. March (DOY 60) through September (DOY 273) rainfall during the three growing seasons and the FI applied irrigations in each season.

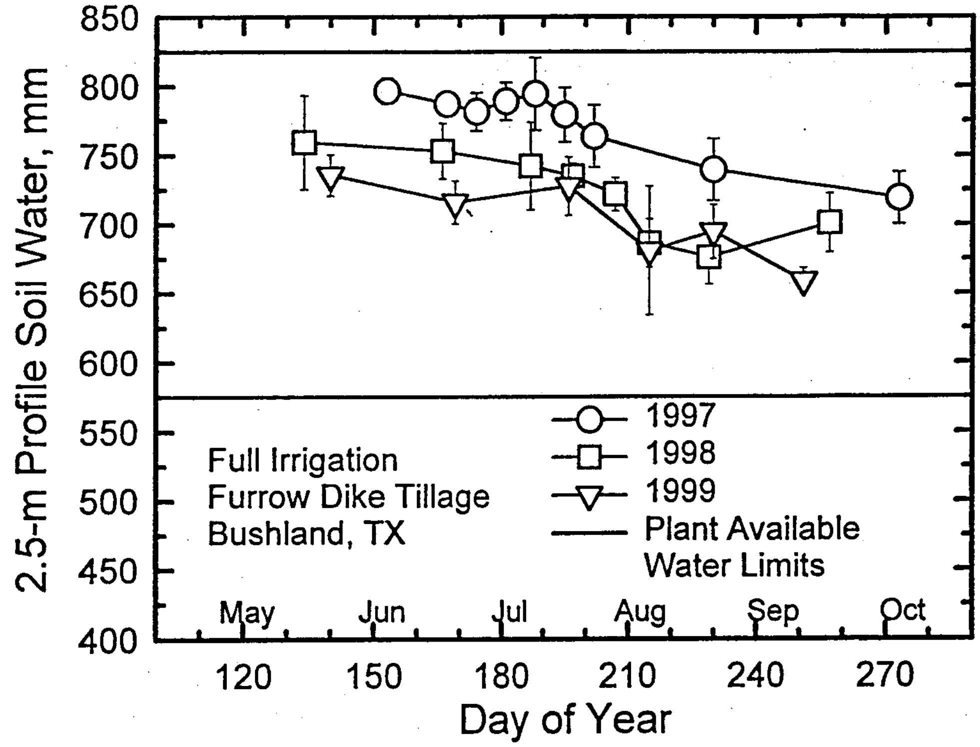

Figure 2. Soil water in the 2.5-m soil profile for the full irrigation, furrow diked treatment in each year. Error bars are standard deviations.